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Hartwell et al.

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(54) **LIQUID QUALITY SYSTEM WITH DRAG-INDUCING PORTIONS**

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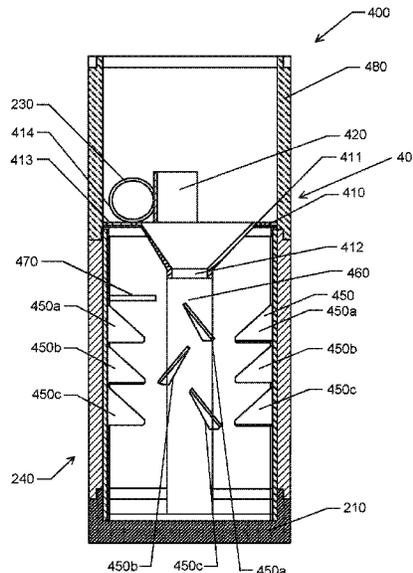
(51) **Int. Cl.**
E03F 5/14 (2006.01)
B01D 21/00 (2006.01)
E03F 5/04 (2006.01)
B01D 21/26 (2006.01)

(57) **ABSTRACT**
The embodiments of the present disclosure provide a system for removing particulates from liquid. The system may comprise a base, a tubular body extending upwardly from the base, a liquid quality device located above the base, a sump region located between the base and the liquid quality device, and a plurality of drag-inducing portions positioned in the sump region and projecting inwardly toward a central axis of the sump region. The tubular body may comprise an inlet and an outlet. The plurality of drag-inducing portions may comprise a first set of drag-inducing portions, a second set of drag-inducing portions, a third set of drag-inducing portions, and a fourth set of drag-inducing portions. The first, second, third, and fourth sets of drag-inducing portions may be positioned equidistant from each other and at a same height around a perimeter of the sump region.

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(58) **Field of Classification Search**
CPC B01D 21/0042; B01D 21/0087; B01D 21/265; E03F 5/0403; E03F 5/14; C02F 2103/001
USPC 210/170.03, 519, 521, 532.1, 747.2, 801
See application file for complete search history.

16 Claims, 18 Drawing Sheets



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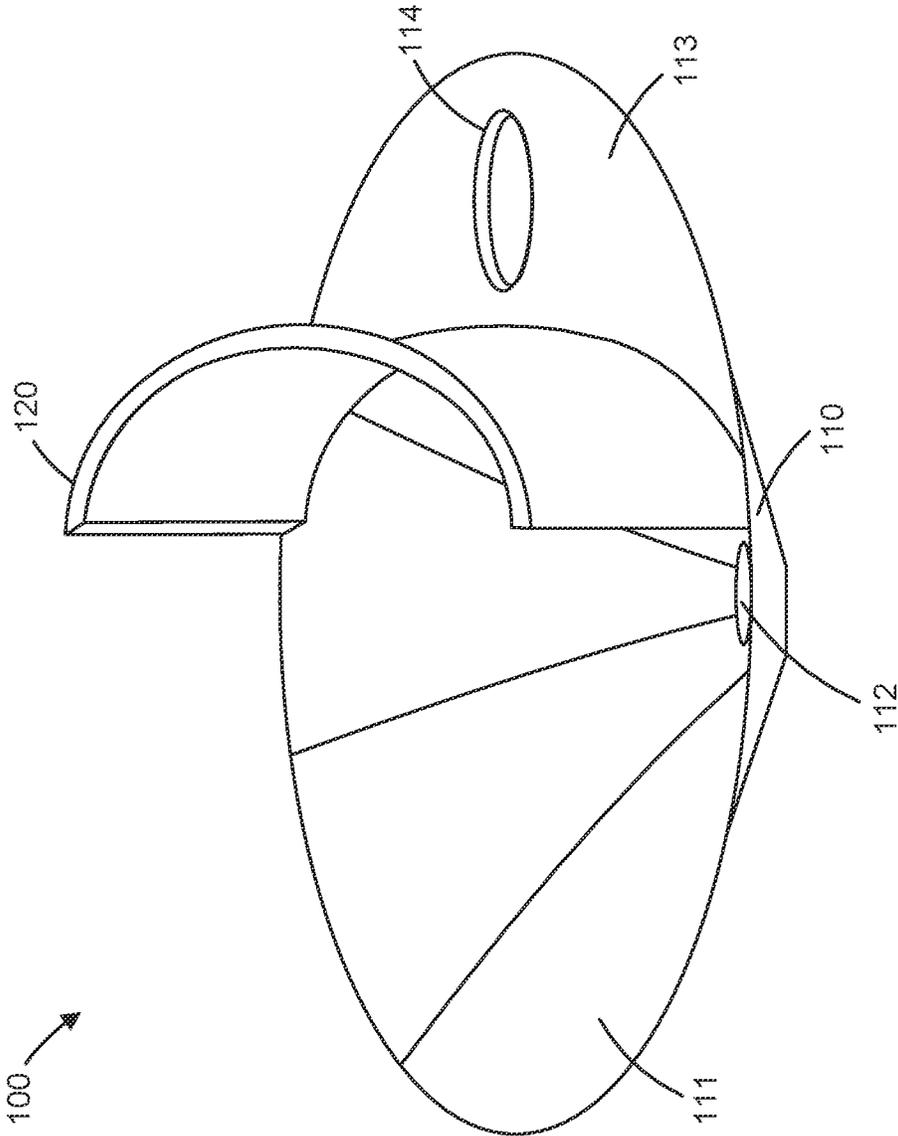


FIG. 1

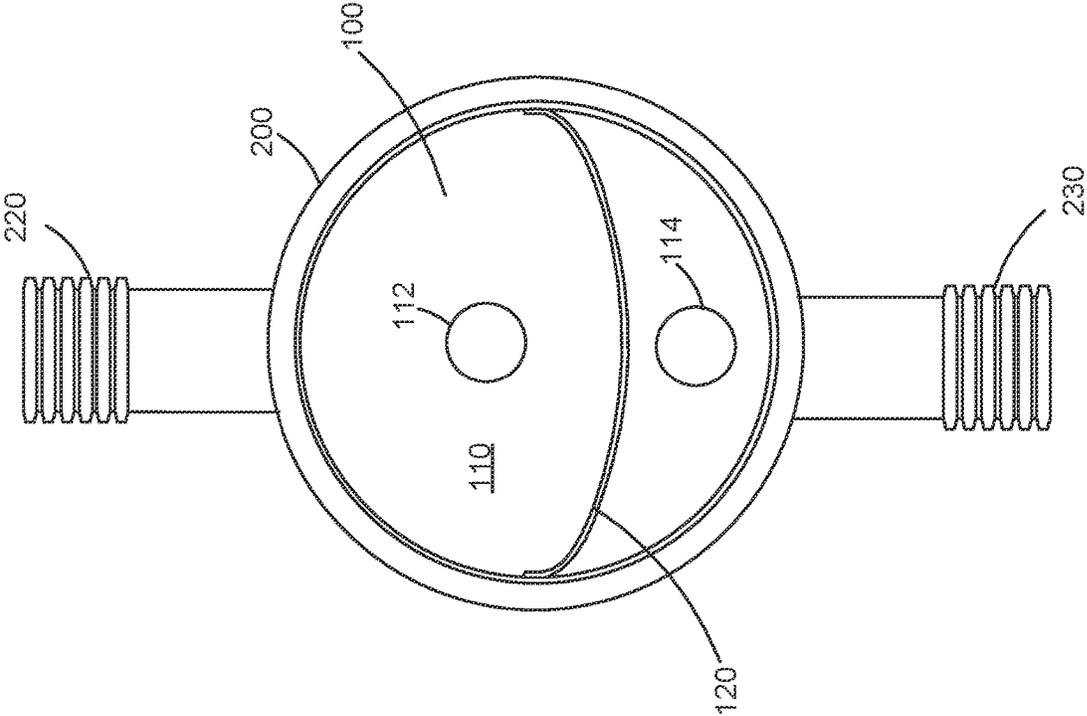


FIG. 2A

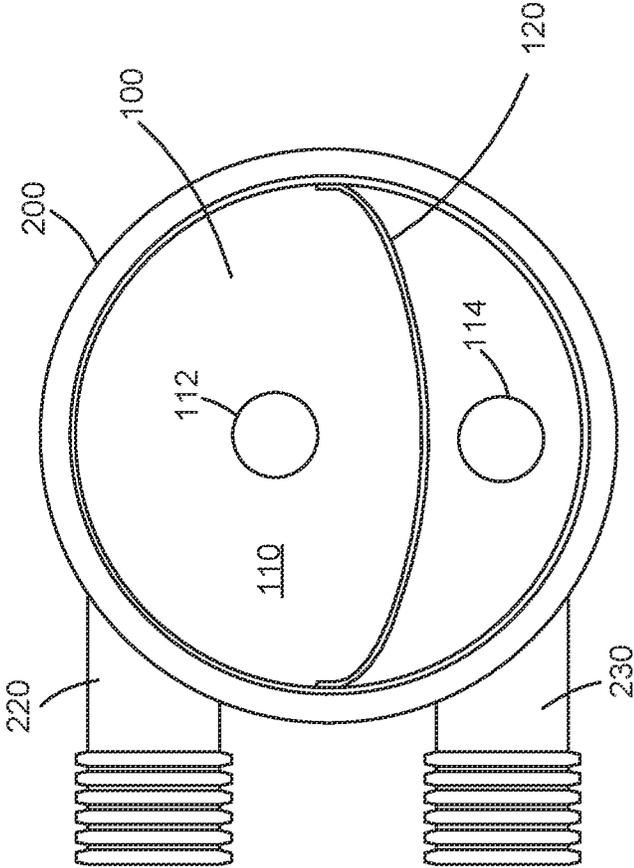


FIG. 2B

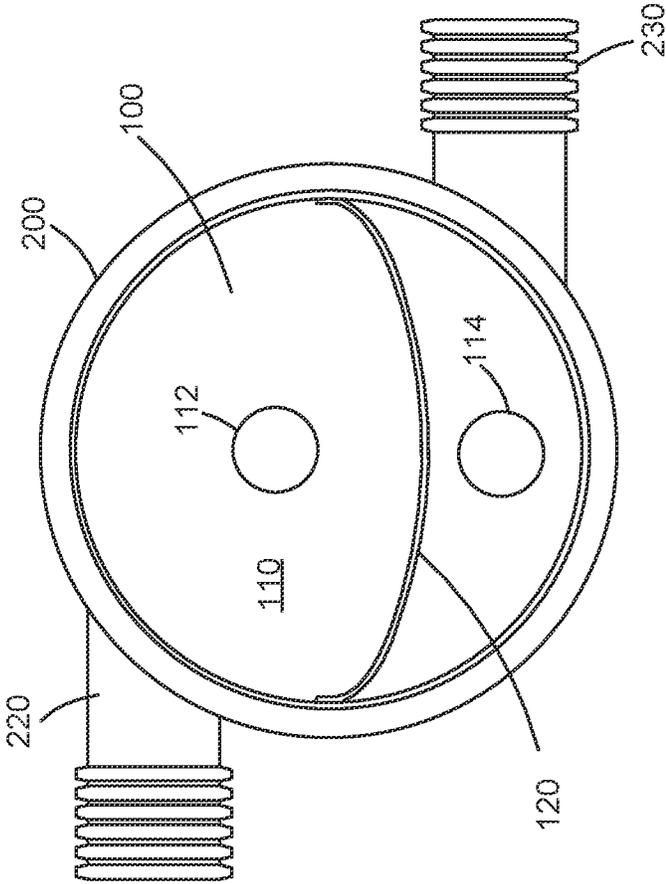


FIG. 2C

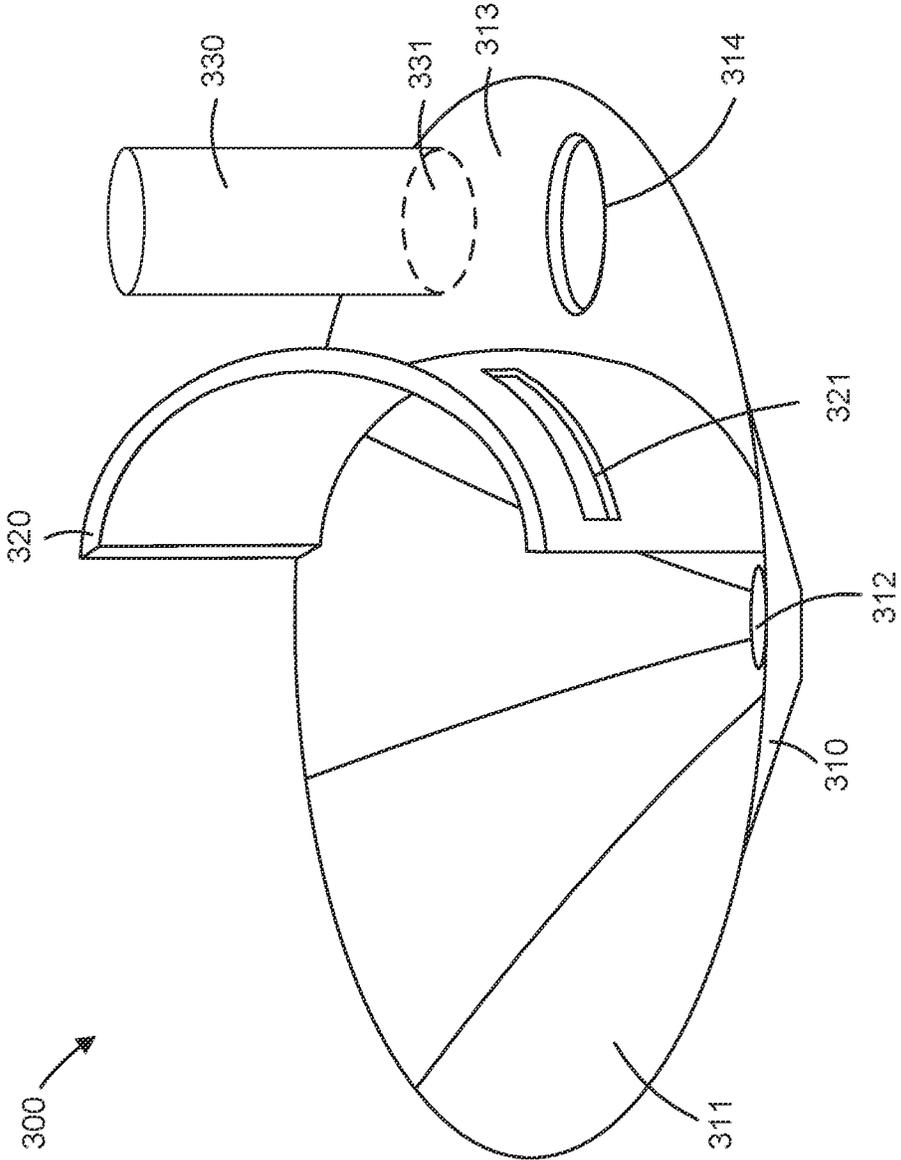


FIG. 3

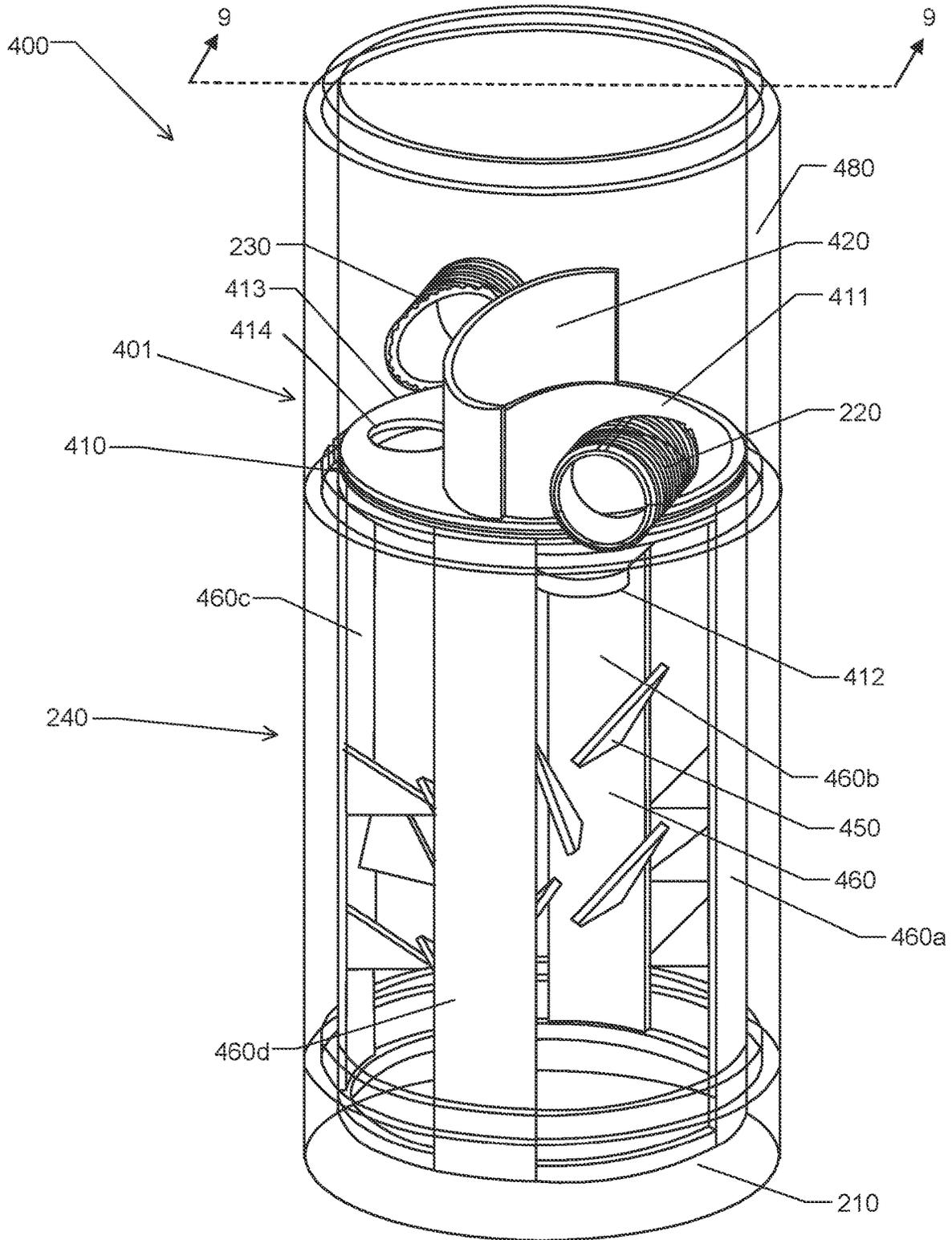


FIG. 4

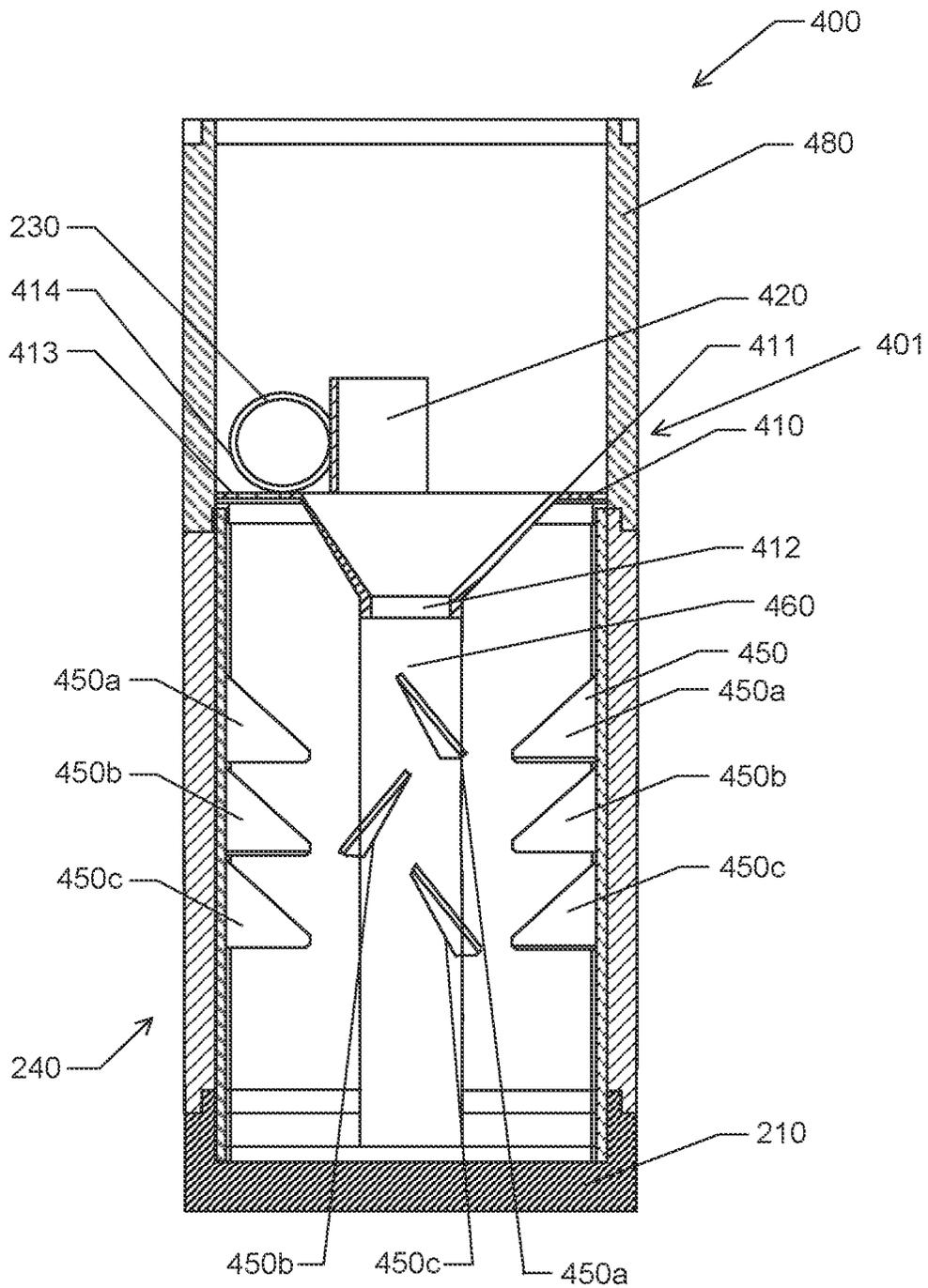


FIG. 5

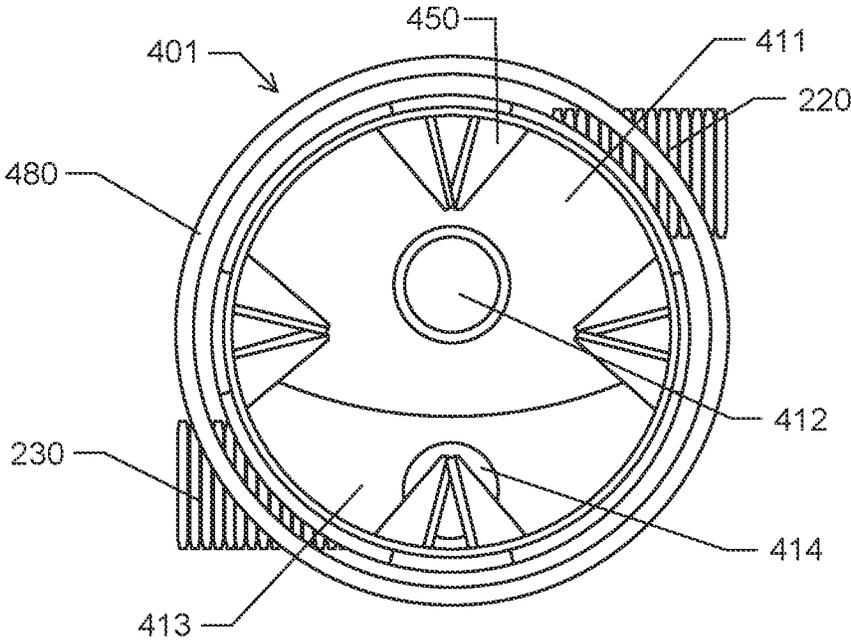


FIG. 6

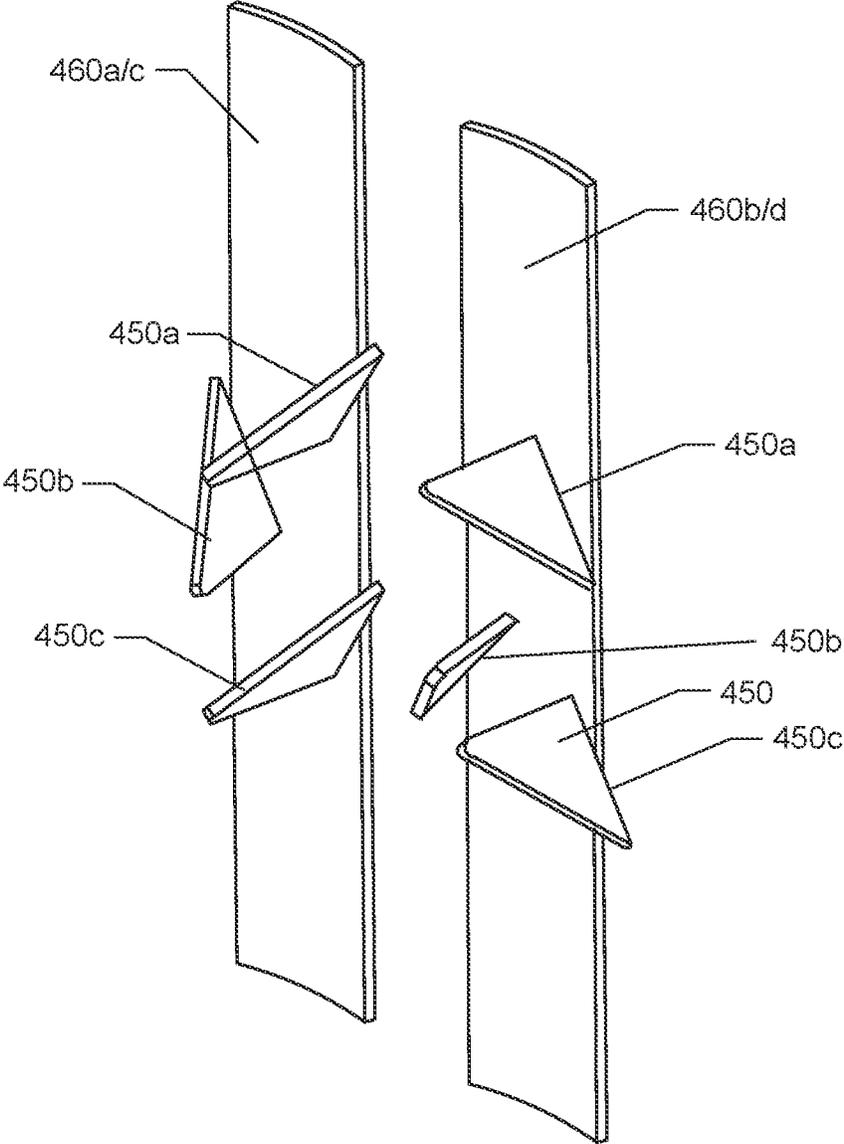


FIG. 7

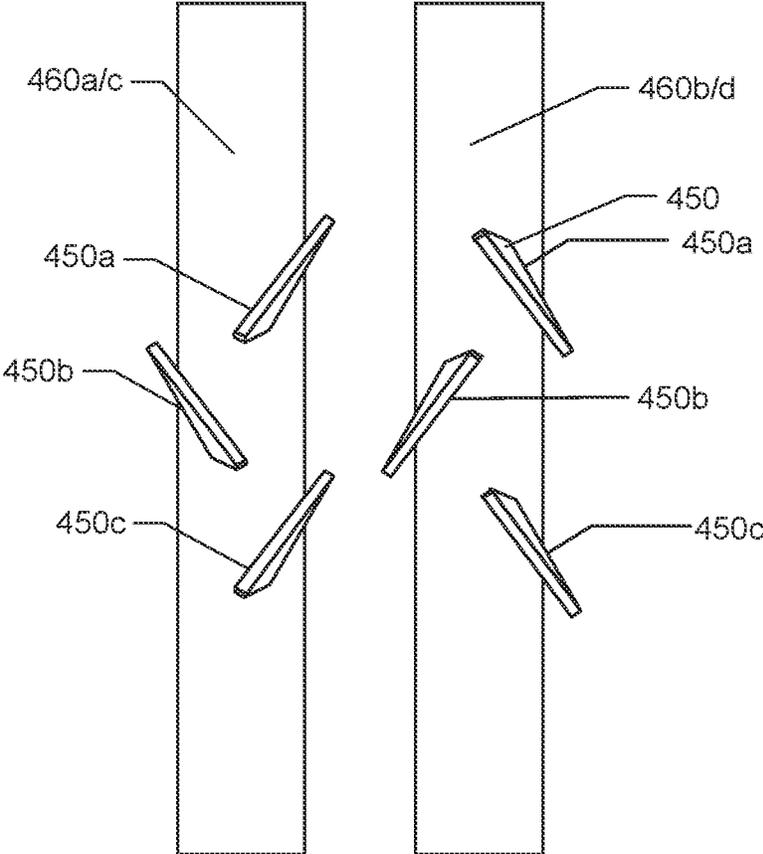


FIG. 8

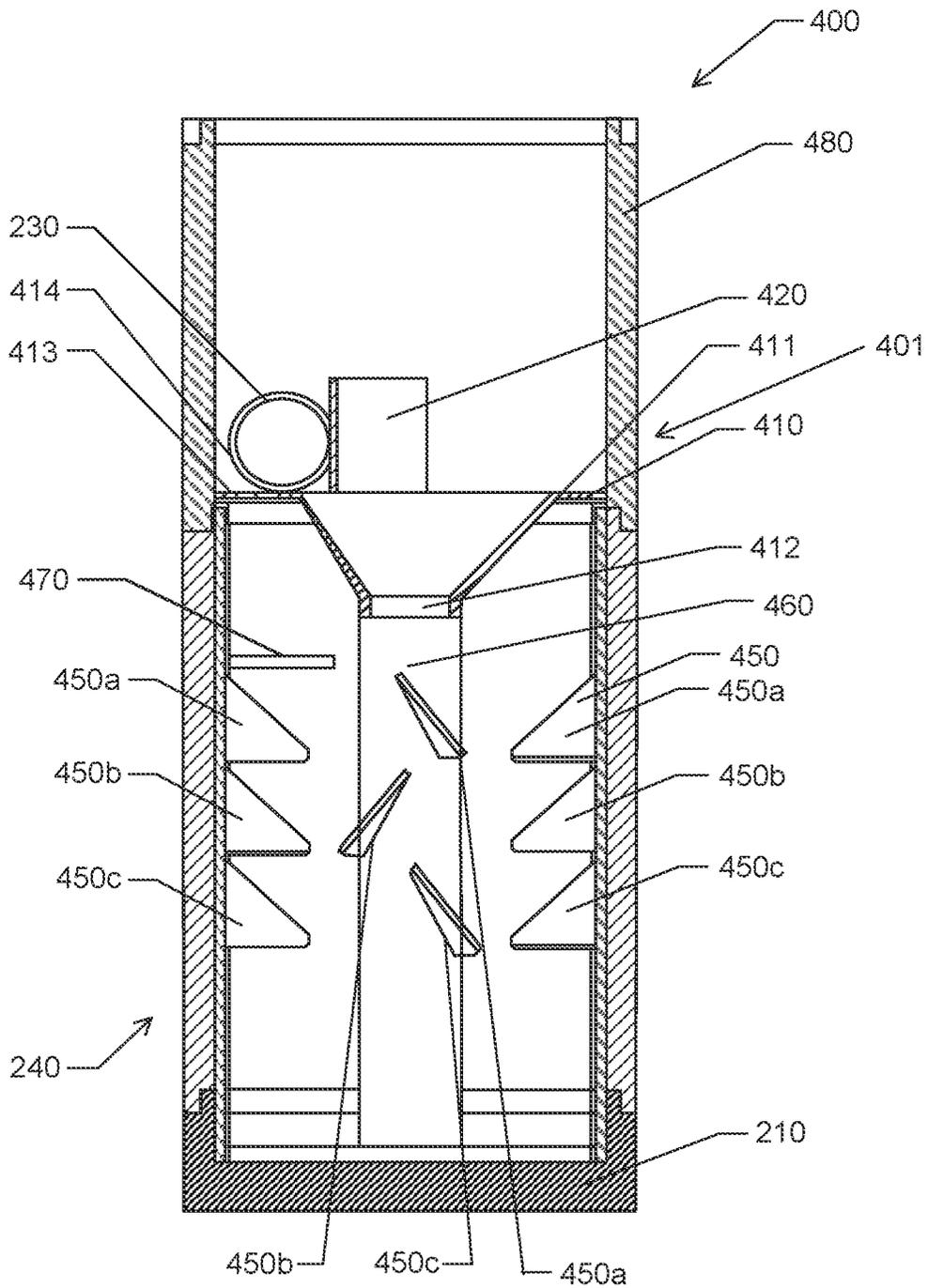


FIG. 9

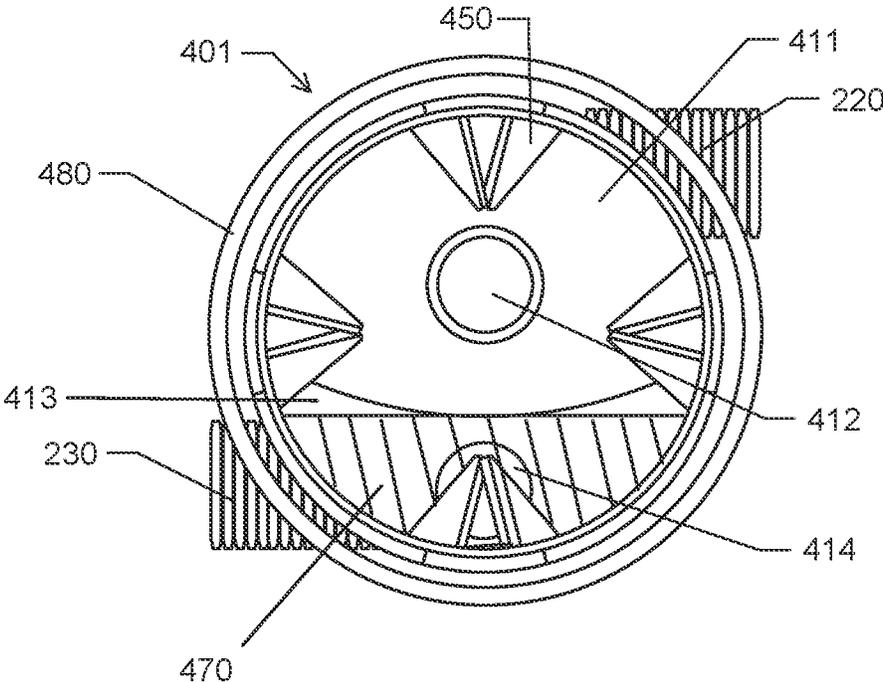


FIG. 10

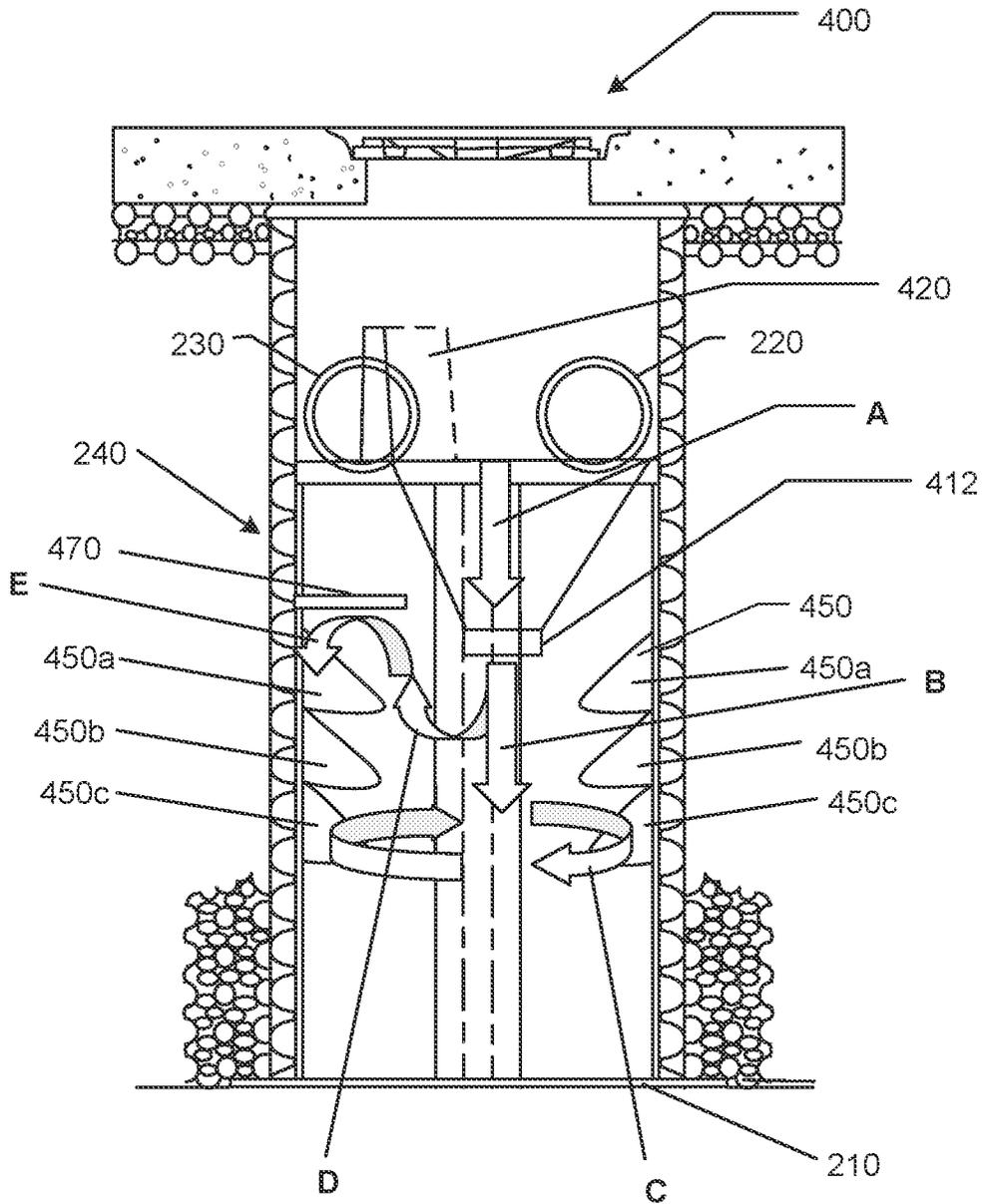


FIG. 11

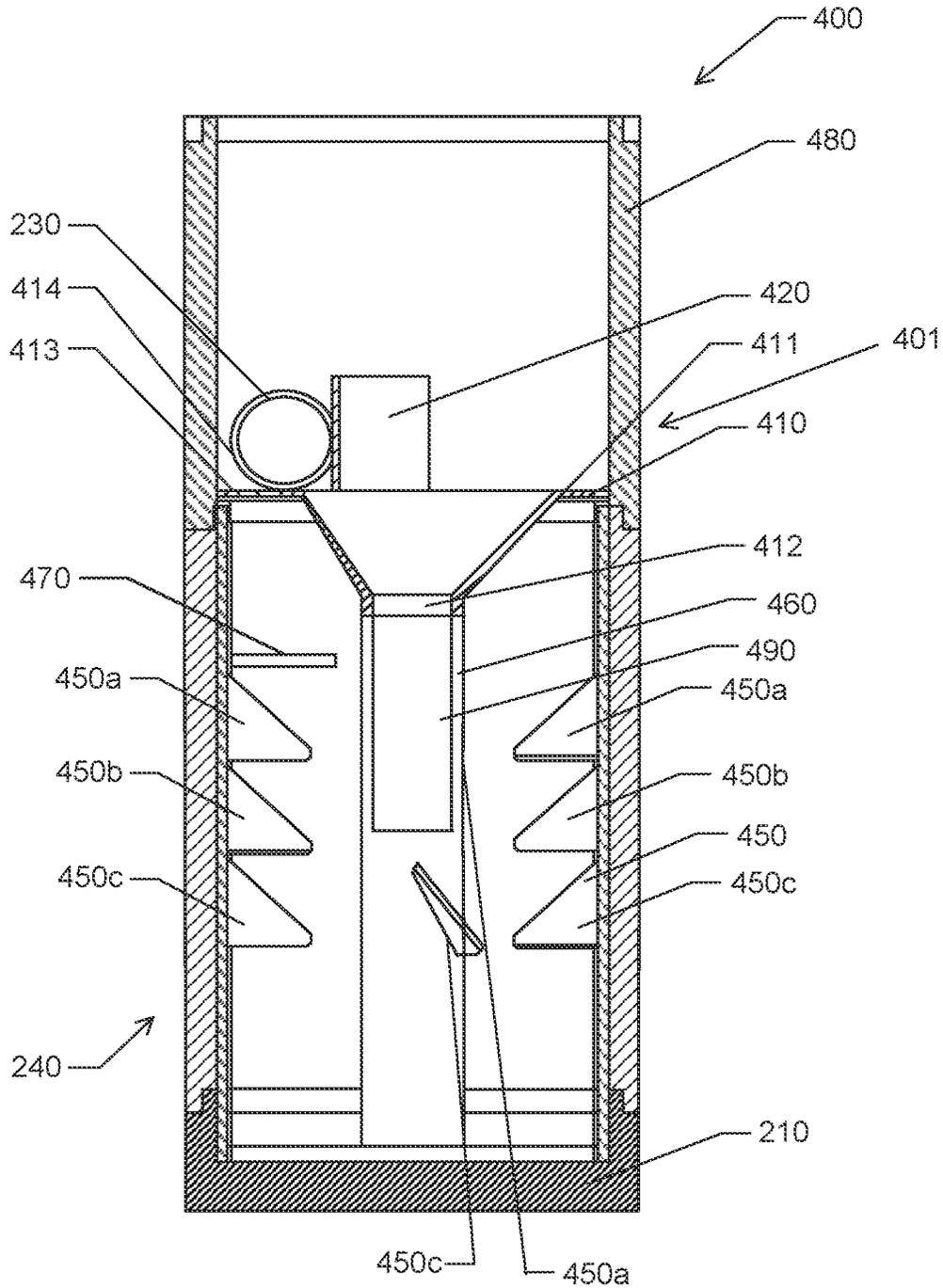


FIG. 12

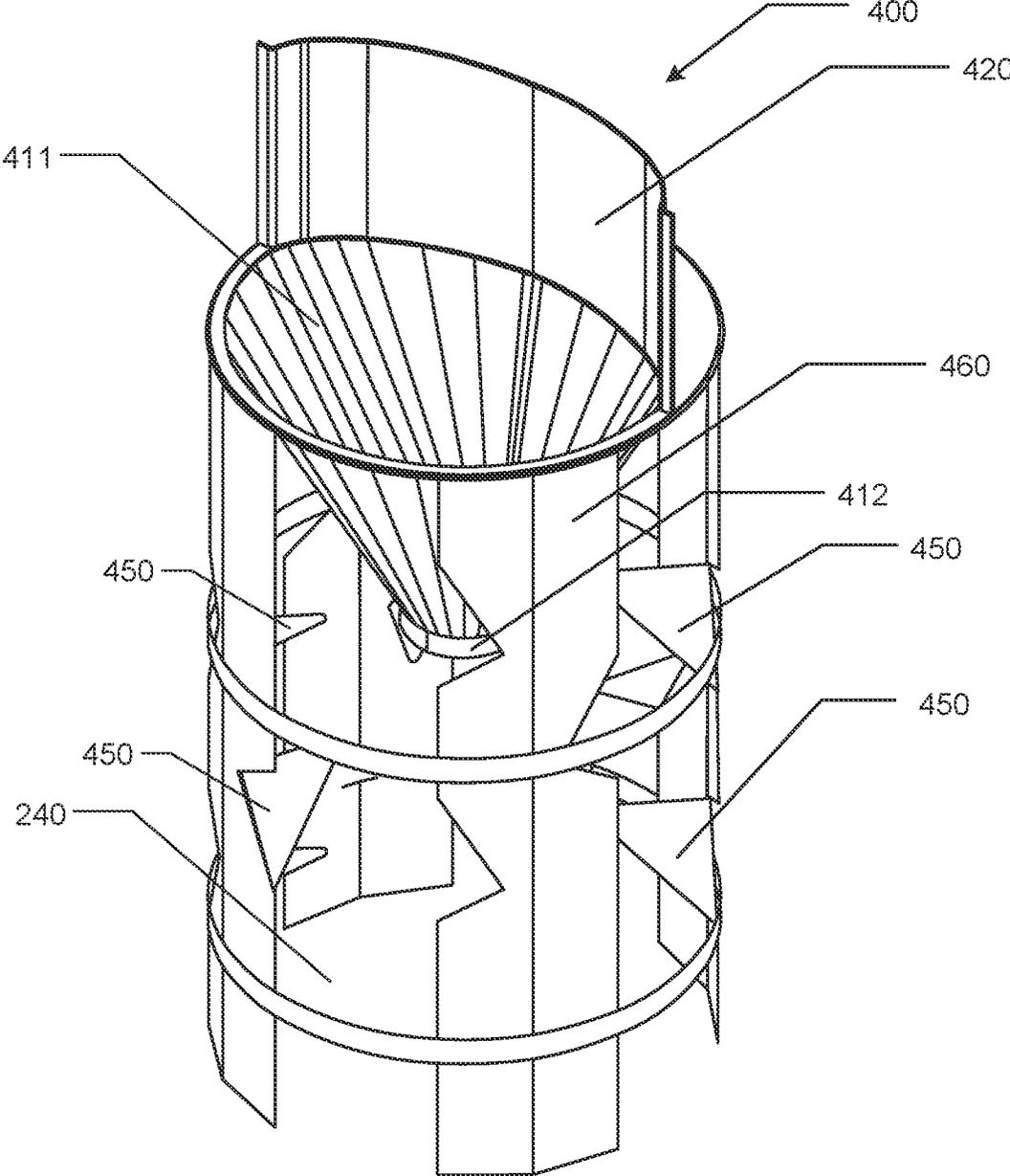


FIG. 14A

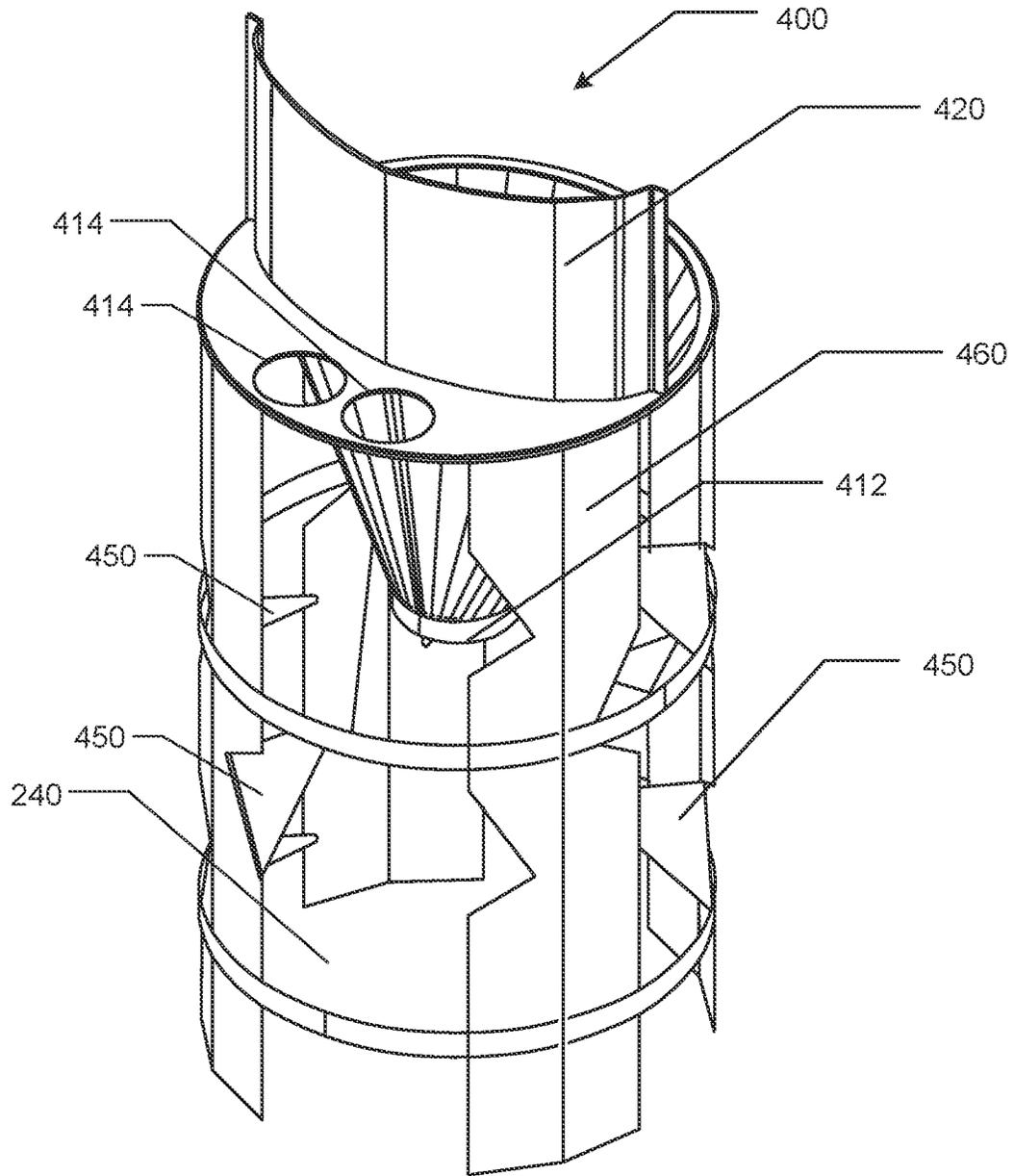


FIG. 14B

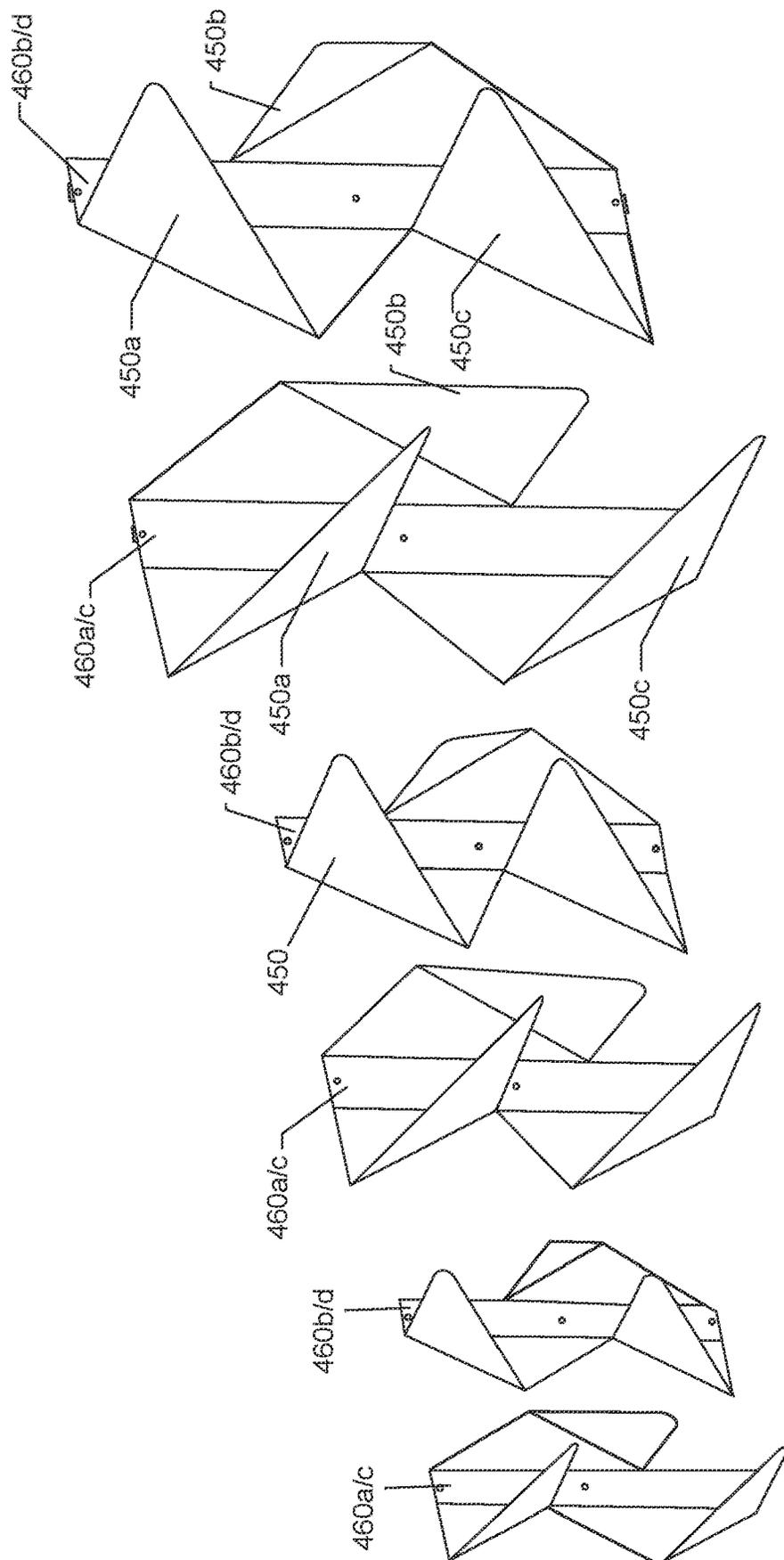


FIG. 15

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LIQUID QUALITY SYSTEM WITH DRAG-INDUCING PORTIONS

TECHNICAL FIELD

This disclosure relates generally to systems for removing particulates from liquid, and more particularly, to systems comprising a liquid quality device and a plurality of drag-inducing portions in a sump region for removing particulates from liquid.

BACKGROUND

Stormwater management systems are used to manage and treat stormwater, for example, by providing stormwater chambers in which sediment, debris, pollutants, or particulates may be removed from stormwater. As such, stormwater chambers may be provided underground where the chambers capture stormwater to separate and retain particulates until they are deposited in the ground or in an off-site location.

Often times, however, conventional stormwater management systems cannot prevent the flow of liquid, such as stormwater runoff, from flooding in the chambers. For example, when a stormwater chamber is filled with stormwater runoff, the systems may no longer be able to capture stormwater and retain particulates until they can be deposited in the ground or in an off-site location later. Accordingly, because conventional stormwater management systems run the risk of flooding, it is challenging for conventional stormwater management systems to reduce particulates from stormwater runoff and, ultimately, prevent particulates from reaching rivers, ponds, lakes, or the ocean.

Therefore, there is a need for improved systems for removing particulates from liquid, such as stormwater runoff, that are capable of reducing the risk of liquid flooding in the systems. There is also a need for improved systems for removing particulates from liquid that can reduce the risk of particulates escaping the systems.

SUMMARY

Embodiments of the present disclosure may include a system for removing particulates from liquid. The system may comprise a base, a tubular body extending upwardly from the base, a liquid quality device located above the base, a sump region located between the base and the liquid quality device, and a plurality of drag-inducing portions positioned in the sump region and projecting inwardly toward a central axis of the sump region. The tubular body may comprise an inlet and an outlet. In addition, the plurality of drag-inducing portions may comprise a first set of drag-inducing portions, a second set of drag-inducing portions, a third-set of drag-inducing portions, and a fourth set of drag-inducing portions. The first, second, third, and fourth sets of drag-inducing portions may be positioned equidistant from each other and at a same height around a perimeter of the sump region.

In some embodiments, the system may further comprise a plate positioned in the sump region between the liquid quality device and the plurality of drag-inducing portions. The plate may be attached to an internal surface of the tubular body and may project inwardly toward the central axis of the sump region. In some embodiments, the plate may project inwardly toward the central axis of the sump region such that the plate partially covers a horizontal, cross-sectional area of the sump region.

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In other embodiments, the liquid quality device may further comprise a first region comprising a funnel with a sump inlet aperture, a second region comprising a sump outlet aperture, and a weir positioned between the first region and the second region. The system may further comprise a tube positioned below the sump inlet aperture. In some embodiments, the tube may extend downwardly from the sump inlet aperture into the sump region. In other embodiments, the first region may be configured to receive a flow of liquid from the inlet of the tubular body and transfer the flow of liquid through the sump inlet aperture of the funnel and into the sump region. Additionally, the second region may be configured to receive the flow of liquid from the sump region through the sump outlet aperture and transfer the flow of liquid to the outlet of the tubular body.

In some embodiments, at least one of the first, second, third, or fourth sets of drag-inducing portions may further comprise a first tooth, a second tooth located below the first tooth, and a third tooth located below the second tooth. In some embodiments, teeth of the first set of drag-inducing portions may be positioned in a different orientation than teeth of the second set of drag-inducing portions. In other embodiments, the first, second, third, and fourth sets of drag-inducing portions may be attached to respective supporting portions positioned proximate the tubular body in the sump region.

According to another embodiment of the present disclosure, a system for removing particulates from liquid is provided. The system may comprise a base, a tubular body extending upwardly from the base, a liquid quality device located above the base, a sump region located between the base and the liquid quality device, a plurality of drag-inducing portions positioned in the sump region and projecting inwardly toward a central axis of the sump region, a plate positioned in the sump region between the liquid quality device and the plurality of drag-inducing portions, and a tube positioned below the sump inlet aperture. The tubular body may comprise an inlet and an outlet. In addition, the liquid quality device may comprise a first region comprising a funnel with a sump inlet aperture, a second region comprising a sump outlet aperture, and a weir positioned between the first region and the second region. Additionally, the tube may extend downwardly from the sump inlet aperture into the sump region.

In some embodiments, the plurality of drag-inducing portions may comprise a first set of drag-inducing portions, a second set of drag-inducing portions, a third set of drag-inducing portions, and a fourth set of drag-inducing portions. The first, second, third, and fourth sets of drag-inducing portions may be positioned equidistant from each other and at a same height around a perimeter of the sump region. In some embodiments, at least one of the first, second, third, or fourth sets of drag-inducing portions may further comprise a first tooth, a second tooth located below the first tooth, and a third tooth located below the second tooth. In some embodiments, teeth of the first set of drag-inducing portions may be positioned in a different orientation than teeth of the second set of drag-inducing portions. In other embodiments, the first, second, third, and fourth sets of drag-inducing portions may be attached to respective supporting portions positioned proximate the tubular body in the sump region.

In some embodiments, the plate may project inwardly toward the central axis of the sump region such that the plate partially covers a horizontal, cross-sectional area of the sump region. In yet another embodiment, the first region may be configured to receive a flow of liquid from the inlet

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of the tubular body and transfer the flow of liquid through the sump inlet aperture of the funnel and into the sump region, and the second region may be configured to receive the flow of liquid from the sump region through the sump outlet aperture and transfer the flow of liquid to the outlet of the tubular body. In some embodiments, the tube may be configured to extend between about 2 inches and about 20 inches downwardly from the sump inlet aperture into the sump region.

According to yet another embodiment of the present disclosure, a system for removing particulates from liquid is provided. The system may comprise a base, a tubular body extending upwardly from the base, a liquid quality device located above the base, a sump region located between the base and the liquid quality device, a plurality of sets of drag-inducing portions positioned equidistant from each other and at a same height around a perimeter of the sump region, a plate positioned in the sump region between the liquid quality device and the plurality of sets of drag-inducing portions, and a tube positioned below the sump inlet aperture. The tubular body may comprise an inlet and an outlet. In addition, the tube may extend downwardly from the sump inlet aperture into the sump region. Additionally, the liquid quality device may comprise a first region comprising a funnel with a sump inlet aperture, a second region comprising a sump outlet aperture, and a weir positioned between the first region and the second region.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate disclosed embodiments and, together with the description, serve to explain the disclosed embodiments.

FIG. 1 is an illustration of a perspective view of an exemplary liquid quality device, consistent with the embodiments of the present disclosure;

FIG. 2A is an illustration of a top view of an exemplary system with a liquid quality device, consistent with the embodiments of the present disclosure;

FIG. 2B is an illustration of a top view of another exemplary system with a liquid quality device, consistent with the embodiments of the present disclosure;

FIG. 2C is an illustration of a top view of another exemplary system with a liquid quality device, consistent with the embodiments of the present disclosure;

FIG. 3 is an illustration of another exemplary liquid quality device, consistent with the embodiments of the present disclosure;

FIG. 4 is an illustration of a perspective view of an exemplary system with a plurality of drag-inducing portions, consistent with the embodiments of the present disclosure;

FIG. 5 is an illustration of a cross-sectional view of the exemplary system of FIG. 4 taken along line 9-9, consistent with the embodiments of the present disclosure;

FIG. 6 is an illustration of a bottom view of the exemplary system of FIG. 4, consistent with the embodiments of the present disclosure;

FIG. 7 is an illustration of a perspective view of a plurality of drag-inducing portions, consistent with the embodiments of the present disclosure;

FIG. 8 is an illustration of a front view of the plurality of drag-inducing portions of FIG. 7, consistent with the embodiments of the present disclosure;

FIG. 9 is an illustration of a cross-sectional view of another exemplary system with a plate positioned above a

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plurality of drag-inducing portions, consistent with the embodiments of the present disclosure;

FIG. 10 is an illustration of a bottom view of the exemplary system of FIG. 9, consistent with the embodiments of the present disclosure;

FIG. 11 is an illustration of a sequence showing how fluid flows through the exemplary system of FIG. 9, consistent with the embodiments of the present disclosure;

FIG. 12 is an illustration of a cross-sectional view of another exemplary system with a plate positioned above a plurality of drag-inducing portions and a tube, consistent with the embodiments of the present disclosure;

FIG. 13 is an illustration of a sequence showing how fluid flows through the exemplary system of FIG. 12, consistent with the embodiments of the present disclosure;

FIG. 14A is an illustration of a front perspective view of another exemplary system, consistent with the embodiments of the present disclosure;

FIG. 14B is a rear perspective view of the exemplary system of FIG. 14A; and

FIG. 15 is an illustration of exemplary drag-inducing portions, consistent with the embodiments of the present disclosure.

DETAILED DESCRIPTION

Reference will now be made in detail to the present embodiments (exemplary embodiments) of the disclosure, examples of which are illustrated in the accompanying drawings.

As discussed in further detail below, various embodiments of a system for removing particulates from liquid, such as stormwater runoff, are provided. The system, consistent with the embodiments of the present disclosure, may be used to reduce particulates in liquid by inducing a vortex in the liquid, causing suspended particulates to settle on the outside of the vortex in a sump region of the system. Accordingly, the system may be able to separate the liquid from the particulates. However, if the velocity of the vortex is too great, the liquid flow may be every turbulent and the settled particulates may be mixed into the liquid again before exiting the system.

The exemplary system for removing particulates from liquid, consistent with the embodiments of the present disclosure, may be better adapted to remove particulates from liquid by reducing the speed of the vortex, directing the liquid flow away from the outlet of the system, subjecting the vortex to drag, thereby decreasing the velocities within the vortex, and/or reducing the lateral movement of the liquid flow. These techniques may improve the effectiveness of the system, as will be described in further detail below.

Turning now to the drawings, FIG. 1 illustrates a perspective view of an exemplary liquid quality device 100, consistent with the embodiments of the present disclosure. The liquid quality device 100 may comprise a partitioning portion 110 and a weir 120. The partitioning portion 110 may comprise a first region 111 and a second region 113, which may be separated by the weir 120. The components of the partitioning portion 110, such as the first region 111, the second region 113, and/or the weir 120, may be one integrated piece. In other embodiments, the components of the partitioning portion 110, such as the first region 111, the second region 113, and/or the weir 120, may be formed from separate pieces. The partitioning portion 110 and/or the weir 120 may be formed of a material, such as polyethylene, polypropylene, or other thermoplastics, or metals, such as stainless steel or aluminum, or fiberglass.

In some embodiments, the weir **120** may at least partially separate the first region **111** from the second region **113**. As seen in FIG. **1**, for example, the weir **120** may comprise a curvature along a horizontal dimension, which may be concave when viewed from the first region **111**. The curvature of the weir **120** may be constant. In other embodiments, the curvature of the weir **120** may have a curve with a varying radius (as shown in FIG. **1**). For example, the curvature of the weir **120** may have shorter radiuses at the edges and one or more longer radiuses in the center. Such a varying-radius design of the curvature of the weir **120** may facilitate the creation of a relatively smooth transition between the weir **120** and a sidewall of a tubular body of a system for removing particulates from liquid. The varying curvature may also assist in reducing turbulence, which may negatively impact the efficiency of the liquid quality device **100** to remove particulates from liquid. In other embodiments, the weir **120** may have no curvature. In yet another embodiment, the weir **120** may have a convex curvature when viewed from the first region **111**.

In some embodiments, the first region **111** may comprise a funnel and a sump inlet aperture **112**. The funnel may be configured to increase the length of time that the liquid flow remains in the funnel, and thus, in a vortex. Additionally or alternatively, the funnel may gradually decrease in radius as the liquid flows down the funnel. Accordingly, the funnel may be configured to maximize particulate separation. The second region **113** may comprise a sump outlet aperture **114**. The second region **113** may also comprise a generally flat profile in the horizontal dimension. The sizes of the sump inlet aperture **112** and the sump outlet aperture **114** may be determined using the following equation:

$$Q = C_d A \sqrt{2gh}$$

where Q is the flow rate in cubic feet per second, A is the area of the respective aperture in square feet, g is the acceleration of gravity (32.2 ft/s^2), and h is the head in feet acting on the respective aperture.

FIGS. **2A-2C** illustrate a top view of various embodiments of an exemplary system **200** comprising the liquid quality device **100** of FIG. **1**, consistent with the embodiments of the present disclosure. System **200** may comprise a base **210** (shown in FIG. **4**), an inlet **220**, and an outlet **230**. In some embodiments, the base **210**, the inlet **220**, and/or the outlet **230** may be integrated into the body of system **200**. In other embodiments, the base **210**, the inlet **220**, and/or the outlet **230** may be formed of separate pieces that may be coupled to each other to form system **200**.

Referring to FIG. **2A**, when liquid, such as stormwater runoff, enters system **200**, the liquid may enter system **200** on one side through the inlet **220** and flow through the sump inlet aperture **112** into a sump region. Then, the liquid may flow from the sump region through the sump outlet aperture **114** and exit system **200** on an opposite side through the outlet **230**. In other embodiments, liquid may enter and exit system **200** on the same side. For example, referring to FIG. **2B**, the liquid may enter system **200** on one side through the inlet **220** and flow through the sump inlet aperture **112** into a sump region. Then, the liquid may flow from the sump region through the sump outlet aperture **114** and exit system **200** on the same side through the outlet **230**. In yet another embodiment, the inlet **220** and the outlet **230** may be located on opposite sides of system **200** and may be offset relative to each other in a horizontal direction. For example, referring to FIG. **2C**, the inlet **220** and the outlet **230** may be offset relative to each other in a horizontal direction, as compared to the positions of the inlet **220** and the outlet **230**

in FIG. **2A**. Other arrangements of the inlet **220** and the outlet **230** may be possible. For example, the inlet **220** and the outlet **230** may be positioned at right angles or oblique angles relative to each other.

FIG. **3** illustrates another exemplary liquid quality device **300**, consistent with the embodiments of the present disclosure. The liquid quality device **300** may comprise a partitioning portion **310** and a weir **320**. The partitioning portion **310** may comprise a first region **311** and a second region **313**, which may be separated by the weir **320**. In some embodiments, the weir **320** may at least partially (or completely) separate the first region **311** from the second region **313**. The first region **311** may comprise a funnel and a sump inlet aperture **312**, and the second region **313** may comprise a sump outlet aperture **314**. In some embodiments, the second region **313** may comprise a generally flat profile in the horizontal dimension.

In some embodiments, the first region **311**, the second region **313**, and/or the weir **320** may be integrated into one piece. In other embodiments, the first region **311**, the second region **313**, and/or the weir **320** may be formed of separate pieces and coupled to each other to form the liquid quality device **300**. In some embodiments, the liquid quality device **300** may further comprise a clean-out riser pipe **330** extending upwardly from an additional aperture **331** in the second region **313**. In some embodiments, a vacuum may be applied through the clean-out riser pipe **730** in order to remove settled particulates in a sump region, such as sump region **240** in FIG. **4**.

In other embodiments, the weir **320** may comprise an aperture **321**. Aperture **321** may be sized and positioned to allow an increased flow rate that falls between a design treatment flow rate and an ultimate flow rate (approximately $3 \times$ the design treatment flow rate) to pass through the aperture **321** without overtopping the entire weir **320**. The design treatment flow rate may be the flow rate of liquid that is intended to pass through the unit and receive treatment for the removal of particulates. The ultimate flow rate may be the total flow rate of the liquid that can pass through the unit without overflowing from the system. By preventing the liquid flow from overtopping the weir **320**, the liquid quality device **300** may be able to assist in containing large debris and forcing large debris into the sump region. It is noted, however, that as the flow rates in the liquid quality device **300** approach the ultimate flow rate, some additional liquid volume in the liquid quality device **300** may overtop the weir **320** and exit the liquid quality device **300**. At this point, however, the liquid may be typically considered to have substantially reduced levels of particulates therein. Therefore, there may be no need for treatment of the liquid at this point. In addition, by allowing the liquid flow to overtop the weir **320** at a particular point, the liquid quality device **300** may be capable of reducing velocities in the sump region, which in turn may help to reduce the re-suspension of previously collected particulates.

FIGS. **4-8** illustrate a system **400** comprising a base **210**, a tubular body **480** extending upwardly from the base **210**, a liquid quality device **401**, and a sump region **240** between the base **210** and the liquid quality device **410**. The liquid quality device **401** may comprise a partitioning portion **410** and a weir **420**. The partitioning portion **410** may comprise a first region **411** and a second region **413**, which may be separated by weir **420**. As discussed above, the system **400** may comprise a tubular body **480**. The tubular body **480** may extend upwardly from the base **210** of system **400** and may comprise an inlet **220** and an outlet **230**.

In some embodiments, the system **400** may comprise a central vertical axis that runs the primary length of the system **400** through the sump region **240**. The system **400** may further comprise at least one drag-inducing portion **450** and at least one supporting portion **460**. In some embodiments, the at least one drag-inducing portion **450** may be attached to the at least one supporting portion **460**. In other embodiments, the at least one drag-inducing portion **450** and the at least one supporting portion **460** may be integrated into one piece. The at least one drag-inducing portion **450** may assist in reducing the liquid flow velocity and turbulence in the vortex that may develop in the sump region **240**. Accordingly, the at least one drag-inducing portion **450** may prevent settled particulates from mixing back up into the liquid, thereby improving the effectiveness of the system **400** in removing particulates from the liquid.

The at least one drag-inducing portion **450** may require a particular flow rate to begin affecting the flow of the liquid in the sump region **240**. For example, at lower flow rates, the funnel may create a vortex in the liquid in the first region **411**, causing liquid to flow through the sump inlet aperture **412** and flow straight down into the sump region **240**. As the flow rate increases, the rotational energy of the liquid may also increase. Therefore, at higher flow rates, the vortex created in the liquid induced by the funnel in the first region **411** may have sufficient rotational energy to create a vortex in the liquid in the sump region **240** after the liquid passes through the sump inlet aperture **412**. Such a vortex in the sump region **240** may have strong turbulence, and the liquid flow velocity and/or the turbulence of the vortex in the sump region **240** may increase as the flow rate increases. As a result of a relatively high flow rate, the turbulent vortex may pick up already settled particulates from the floor of the sump region **240**. In addition to a relatively high liquid flow velocity, liquid turbulence within the vortex may affect the behavior of the liquid flow and may also influence the settling characteristics of particulates in the flow. For example, the greater the liquid turbulence and liquid flow velocity in the sump region **240**, the more difficult it may be for particulates to settle, and the easier it may be for particulates to be re-suspended into the liquid. Therefore, it may be desirable to create a longer, more laminar flow path to increase the amount of time during which liquid remains in the sump region **240**, thereby providing sufficient time for particulates to settle at the base **210**. In some embodiments, system **400** may reduce resuspension of settled particulates in the sump region **240** by transforming the turbulent flow of the vortex into a controlled and increasingly laminar flow. In order to create a longer, more laminar flow path, system **400** may force the liquid to make smooth direction changes as the liquid moves around the sump region **240** in the vortex. Additionally or alternatively, system **400** may guide the liquid flow away from the sump outlet aperture **414** to increase the amount of time that liquid remains in the sump region **240**.

In some embodiments, as seen in FIGS. 4-6, the drag-inducing portions **450** may project inwardly towards the central axis of the system **400** and may be positioned proximate a sidewall of tubular body **480** in the sump region **240**. For example, the drag-inducing portions **450** may be positioned proximate to or on the sidewall of the tubular body **480** in the sump region **240**. The drag-inducing portion **450** may create drag to slow the liquid flow velocities in the vortex, extend the flow path by forcing a smooth direction change, and/or guide liquid away from the sump

outlet aperture **414**. In some embodiments, the orientation and angle of the at least one drag-inducing portion **450** may be adjustable.

In other embodiments, the at least one drag-inducing portion **450** may comprise a solid or a hollow body and may be configured to displace some volume of the liquid in the sump region **240**. For example, when liquid flow passes by the body of the at least one drag-inducing portion **450**, the liquid in the flow may be displaced by the body of the at least one drag-inducing portion **450** and, as a result, a boundary layer may form along the surface of the at least one drag-inducing portion **450**. The boundary layer may result in the liquid changing in viscosity and becoming more dense, thereby directing the liquid downstream until the flow separates. Such displacement of the liquid flow path may facilitate the settling of particulates by allowing the particulates to be knocked out of the vortex flow.

In some embodiments, a plurality of drag-inducing portions **450** may be positioned in the sump region **240** in order to reduce the liquid flow velocity in the vortex and alter the flow path of liquid even more. In some embodiments, the drag-inducing portions **450** may be attached to at least one supporting portion **460**, which may in turn be attached to the sidewall of the sump region **240**. In some embodiments, for example, the drag-inducing portions **450** may be attached to the at least one supporting portion **460** by an adhesive, a screw, or a bolt. In other embodiments, the drag-inducing portions **450** and the at least one supporting portion **460** may be integrated and formed in a single piece. Similarly, the at least one supporting portion **460** may be attached to the sidewall of the sump region **240** by an adhesive, a screw, or a bolt. In other embodiments, the at least one supporting portion **460** and the sidewall of the sump region **240** may be integrated and formed in a single piece. In yet another embodiment, the drag-inducing portions **450** may be directly attached to the sidewall of the sump region **240** without the supporting portion **460**.

By way of example, FIGS. 14A and 14B illustrate perspective views of an exemplary embodiment of system **400** comprising a funnel in the first region **411**, a weir **420**, a plurality of drag-inducing portions **450**, and a plurality of supporting portions **460**. In FIGS. 14A and 14B, the funnel in the first region **411**, the weir **420**, the plurality of drag-inducing portions **450**, and the plurality of supporting portions **460** may be integrated and formed in a single piece to form the system **400**. In some embodiments, the funnel in the first region **411**, the weir **420**, the plurality of drag-inducing portions **450**, and the plurality of supporting portions **460** may be formed of a material, such as polyethylene, polypropylene, or other thermoplastics, or metals, such as stainless steel or aluminum, or fiberglass. Additionally or alternatively, the funnel in the first region **411**, the weir **420**, the plurality of drag-inducing portions **450**, and the plurality of supporting portions **460** may be welded together to form the system **400**. In other embodiments, the system **400** may comprise a plurality of sump outlet apertures **414** to guide the liquid flow out of the sump region **240**. For example, as seen in FIG. 14B, the system **400** may comprise two sump outlet apertures **414** to guide the liquid flow out of the sump region **240**.

In some embodiments, the plurality of drag-inducing portions **450** may be made from a single sheet of material, and thus, integrated and formed into a single piece. For example, as shown in FIG. 15, each set of drag-inducing portions **450a**, **450b**, and **450c** may be made from a single sheet of material, such as polyethylene, polypropylene, or other thermoplastics, or metals, such as stainless steel or

aluminum, or fiberglass. In some embodiments, each set of drag-inducing portions **450a**, **450b**, and **450c**, as well as the supporting portion **460a/c** or **460b/d** on which each set of drag-inducing portions **450a**, **450b**, and **450c** are coupled, may be formed from a single piece of material, and thus, integrated into one piece. As seen in FIG. 15, in some embodiments, one or more of the sets of drag-inducing portions **450** may be adjusted in size and one or more of the supporting portions **460a/c** and **460b/d** may be adjusted in length based on a diameter of the system for removing particulates from liquid.

In some embodiments, the drag-inducing portions **450** may comprise one or more triangular-shaped teeth. For example, as used herein, “tooth” or “teeth” may refer to individual drag-inducing portions **450**. The terms “tooth” and “teeth” are not limited to triangular shapes. For example, the drag-inducing portions **450** may comprise teeth of other geometrical shapes, including but not limited to, rectangles, squares, ovals, circles, or other various polygons. In some embodiments, the at least one supporting portion **460** may comprise vertical strips that may be positioned between the partitioning portion **410** and the base **210** proximate the sidewall of the tubular body **480** in the sump region **240**. In some embodiments, the plurality of supporting portions **460** may be spaced equidistant around a perimeter of the sump region **240** such that sets of drag-inducing portions **450** may be positioned equidistant around a perimeter of the sump region **240**. Additionally or alternatively, the plurality of supporting portions **460** may be positioned irregularly around the perimeter of the sump region **240**.

As shown in FIG. 4, system **400** may comprise a plurality of drag-inducing portions **450**. For example, system **400** may comprise a plurality of sets of drag-inducing portions, such as a first set of drag-inducing portions, a second set of drag-inducing portions, a third set of drag-inducing portions, and a fourth set of drag-inducing portions. The first, second, third, and fourth sets of drag-inducing portions may be positioned equidistant from each other and at a same height around a perimeter of the sump region. In some embodiments, system **400** may comprise any number of sets of drag-inducing portions, such as one to ten sets of drag-inducing portions. As seen in FIG. 5, each set of drag-inducing portions may comprise a first drag-inducing portion **450a**, a second drag-inducing portion **450b**, and a third drag-inducing portion **450c**, each of which may project inwardly toward the central axis and may be positioned proximate the sidewall of the tubular body **480** in the sump region **240**. Each of the first drag-inducing portion **450a**, the second drag-inducing portion **450b**, and the third drag-inducing portion **450c** may be referred to as a tooth. The first drag-inducing portion **450a**, the second drag-inducing portion **450b**, and the third drag-inducing portion **450c** may make up one set of drag-inducing portions **450**. Therefore, as shown in FIGS. 4 and 6, for example, system **400** may comprise four sets of drag-inducing portions **450** respectively attached to a first supporting portion **460a**, a second supporting portion **460b**, a third supporting portion **460c**, and a fourth supporting portion **460d**.

As seen in FIG. 4, supporting portions **460a**, **460b**, **460c**, and **460d** may be positioned equidistant around the perimeter of the sump region **240**. In some embodiments, the vertical positioning of drag-inducing portions **450a**, **450b**, and **450c** may be generally central on each of the supporting portions **460a**, **460b**, **460c**, and **460d**. Additionally or alternatively, each set of drag-inducing portions **450a**, **450b**, and **450c** may be positioned at a same height around a perimeter of the sump region, thereby simplifying the process of

installing drag-inducing portions **450** on the supporting portions **460** and/or the sidewall of the sump region **240**. For example, each drag-inducing portion **450a** positioned around the perimeter of the sump region **240** may be positioned at the same height, each drag-inducing portion **450b** positioned around the perimeter of the sump region **240** may be positioned at the same height, and each drag-inducing portion **450c** positioned around the perimeter of the sump region **240** may be positioned at the same height.

In other embodiments, supporting portions **460a** and **460c** may have a different configuration of drag-inducing portions **450a**, **450b**, and **450c** than supporting portions **460b** and **460d**. For example, the supporting portions **460a** and **460c** may face each other and have a first configuration and orientation of drag-inducing portions **450a**, **450b**, and **450c**, while supporting portions **460b** and **460d** may face each other and have a second, different configuration and orientation of drag-inducing portions **450a**, **450b**, and **450c**.

FIGS. 7 and 8 illustrate a first configuration and a second configuration of a plurality of drag-inducing portions **450**, consistent with the embodiments of the present disclosure. As seen in FIGS. 7 and 8, in the first configuration, the drag-inducing portions **450a**, **450b**, and **450c** may be equidistantly vertically positioned along a primary axial dimension of respective supporting portions **460a**, **460c**. In other embodiments, the drag-inducing portions **450a**, **450b**, and **450c** may be irregularly vertically positioned along a primary axial dimension. As seen in FIGS. 7 and 8, in the first configuration, the drag-inducing portions **450a**, **450b**, and **450c** may each be oriented upwardly. The first drag-inducing portion **450a** and the third drag-inducing portion **450c** may be oriented in the same direction, while the second drag-inducing portion **450b** is oriented in a different direction. For example, the first drag-inducing portion **450a** and the third drag-inducing portion **450c** may be angled 60° from a horizontal plane, while the second drag-inducing portion **450b** may have a mirrored orientation from the first drag-inducing portion **450a** and the third drag-inducing portion **450c**. That is, the second drag-inducing portion **450b** may be angled 120° from the horizontal plane. The first, second, and third drag-inducing portions **450a**, **450b**, and **450c** may be oriented at other various angles from the horizontal plane in the first configuration.

In the second configuration, the drag-inducing portions **450a**, **450b**, and **450c** may be equidistantly vertically positioned along a primary axial dimension of respective supporting portions **460b**, **460d**. In other embodiments, the drag-inducing portions **450a**, **450b**, and **450c** may be irregularly vertically positioned along a primary axial dimension. As seen in FIGS. 7 and 8, in the second configuration, the drag-inducing portions **450a**, **450b**, and **450c** may each be oriented downwardly. The first drag-inducing portion **450a** and the third drag-inducing portion **450c** may be oriented in the same direction, while the second drag-inducing portion **450b** is oriented in a different direction. For example, the first drag-inducing portion **450a** and the third drag-inducing portion **450c** may be angled -60° from a horizontal plane, while the second drag-inducing portion **450b** may have a mirrored orientation from the first drag-inducing portion **450a** and the third drag-inducing portion **450c**. That is, the second drag-inducing portion **450b** may be angled -120° from the horizontal plane. The first, second, and third drag-inducing portions **450a**, **450b**, and **450c** may be oriented at other various angles from the horizontal plane in the second configuration.

The drag-inducing portions **450a**, **450b**, and **450c** in the first configuration may be respectively at the same height as

the drag-inducing portions **450a**, **450b**, and **450c** in the second configuration along the primary axial dimension. For example, as shown in FIG. 8, the first drag-inducing portion **450a** in the first configuration on supporting portion **460a** or **460c** may be at the same height as the first drag-inducing portion **450a** in the second configuration on supporting portion **460b** or **460d** along a primary axial dimension. In addition, the second drag-inducing portion **450b** in the first configuration on supporting portion **460a** or **460c** may be at the same height as the second drag-inducing portion **450b** in the second configuration on supporting portion **460b** or **460d**. Similarly, the third drag-inducing portion **450c** in the first configuration on supporting portion **460a** or **460c** may be at the same height as the third drag-inducing portion **450c** in the second configuration on supporting portion **460b** or **460d**.

The angular position of the drag-inducing portions **450a**, **450b**, and **450c** may be based on the principles of Stoke's Law and "inclined plate settling" techniques. For example, in the embodiment in which the drag-inducing portions **450** are positioned at $+60^\circ$ or -60° , the positioning of the drag-inducing portions **450** may help facilitate particulate settling. An angular positioning of $+60^\circ$ or -60° may also allow particulates to slide down the drag-inducing portions **450** and fall to the bottom of the sump region **240**. The size and orientation of the drag-inducing portions **450** may be determined based on the following equations:

$$t = \frac{w}{v \cos \theta}$$

$$L = \frac{w(V - v \sin \theta)}{v \cos \theta}$$

where w is the settling distance from the inlet aperture to the bottom of the sump region, v is the settling velocity (in/s), θ is the angle of the tubular body from the horizontal plane, and L is the length of the drag-inducing portions, and

$$\frac{du_p}{dt} = F_D(u - u_p) + \frac{g_x(\rho_p - \rho)x^2}{\rho_p} + F_x$$

$$F_D = \frac{18u}{\rho_p d_p^2} \frac{C_D R_p}{24}$$

$$R_p = \frac{\rho d_p |u_p - u|}{\mu}$$

$$c_d = \frac{24}{R_p}$$

where u_p is the particle velocity, u is the fluid velocity, ρ is the fluid density, ρ_p is the particle density, g_x is the gravity, x and F_x are additional forces such as body forces and forces due to pressure gradients, and F_D is the drag force being composed of the liquid molecular velocity μ , the particle diameter d_p , the Reynolds number of the particle R_p , and the drag coefficient C_d .

In some embodiments, the system for removing particulates from liquid may further comprise a plate configured to prevent short-circuiting of the flow of liquid. Referring to FIGS. 9-11, for example, system **400** may further comprise a plate **470** positioned in the sump region **240** between the liquid quality device **401** and the plurality of drag-inducing portions **450**. When liquid, such as stormwater runoff, enters into the sump region **240** via sump inlet aperture **412** and interacts with the plurality of drag-inducing portions **450**, a

vortex is created, which allows particulates in the liquid to fall out of the vortex and into the bottom of the sump region **240** before the liquid exits the system **400**. However, a portion of the liquid flow may never reach the plurality of drag-inducing portions **450** in the sump region **450**, but instead, exit the system **400** without liquid treatment. Accordingly, in order to ensure that the liquid flow reaches the plurality of drag-inducing portions **450** in the sump region **450** and prevent the liquid from exiting the system **400** without treatment, a plate **470** may be positioned above the plurality of drag-inducing portions **450**. The plate **470** may be configured to direct the liquid flow to the plurality of drag-inducing portions **450**, thereby eliminating flow pathways for short-circuiting.

As seen in FIGS. 9 and 10, the plate **470** may comprise a substantially horizontal plate positioned below the sump inlet aperture **412** and above the plurality of drag-inducing portions **450**. The plate **470** may be formed of a material, such as polyethylene, polypropylene, or other thermoplastics, or metals, such as stainless steel or aluminum, or fiberglass. In some embodiments, the plate **470** may be between about 5 inches and about 20 inches wide. For example, the plate **470** may be about 15 inches wide. While FIGS. 9 and 10 illustrate one plate **470** positioned in the sump region **240**, the embodiments of the present disclosure are not limited thereto. For example, system **400** may comprise a plurality of plates **470** positioned above the drag-inducing portions **450** in the sump region **240**, such as two, three, or four plates **470**. In some embodiments, the number of plates **470** in the sump region **240** may be the same as the number of sets of drag-inducing portions **450** in the sump region **240**. By way of example, if there are four sets of drag-inducing portions **450** in the sump region **240**, system **400** may comprise four plates **470**, one above each set of drag-inducing portions **450**.

FIG. 11 illustrates an exemplary sequence showing how liquid flows through system **400**, consistent with the embodiments of the present disclosure. At step A, liquid comprising suspended particulates may enter into the funnel of the liquid quality device, and the funnel, together with the weir **420**, may induce the liquid into a vortex. At step B, the liquid may pass through the liquid quality device via sump inlet aperture **412** and into the sump region **240**. At step C, the liquid propagates into the sump region **240** in a generally horizontal direction, as shown by the arrows. Once the liquid passes into the sump region **240**, the vortex action may be reduced through detention time and energy losses, partly due to the plurality of drag-inducing portions **450** (drag-inducing portions **450a**, **450b**, **450c**, as shown in FIG. 11), thereby allowing smaller particulates that were not removed through the cyclonic action of the vortex in the funnel to settle out of the liquid and into the bottom of the sump region **240**. At step D, however, some of the liquid flow may try to exit the sump region **240** without reaching the plurality of drag-inducing portions **450** (i.e., short-circuiting). Accordingly, the plate **470** may be positioned above the plurality of drag-inducing portions **450** in the sump region **240** in order to direct the liquid flow trying to exit the sump region **240**. For example, at step E, some of the liquid flow trying to exit the sump region **240** may be directed back towards the plurality of drag-inducing portions **450** in the sump region **240** by the plate **470**. Therefore, the plate **470** may ensure that the liquid does not exit the system **400** without treatment to remove particulates from the liquid.

In some embodiments, the system for removing particulates from liquid may further comprise a tube to prevent short-circuiting of the flow of liquid. Referring to FIGS. 12

and 13, for example, system 400 may further comprise a tube 490 positioned below the sump inlet aperture 412, and the tube 490 may extend downwardly from the sump inlet aperture 412 into the sump region 240. For example, the tube 490 may extend between about 2 inches and about 20 inches downwardly from the sump inlet aperture 412. In some embodiments, the tube 490 may extend between about 12 inches and about 20 inches downwardly from the sump inlet aperture 412. The tube 490 may be formed of a material, such as polyethylene, polypropylene, or other thermoplastics, metals, such as stainless steel or aluminum, or fiberglass.

When liquid, such as stormwater runoff, enters through the sump inlet aperture 412, the tube 490 may direct the incoming flow of liquid deeper into the sump region 240, thereby reducing or eliminating lateral movement of the liquid. Accordingly, the tube 490 may direct the liquid flow deeper into the plurality of drag-inducing portions 450 (drag-inducing portions 450a, 450b, and 450c depicted in FIG. 12) in the sump region 240. By directing the liquid deeper into the plurality of drag-inducing portions 450, the tube 490 may ensure that the liquid interacts with the plurality of drag-inducing portions 450 for treatment to remove particulates from the liquid before exiting the system 400, thereby eliminating flow pathways for short-circuiting. As shown in FIG. 12, the system 400 may comprise both the plate 470 and the tube 490 to eliminate liquid flow pathways for short-circuiting and ensure that the liquid receives treatment for removing particulates therein before exiting the system 400. In other embodiments, the system 400 may comprise only the plate 470 or only the tube 490.

FIG. 13 illustrates an exemplary sequence showing how liquid flows through system 400, consistent with the embodiments of the present disclosure. At step A, liquid comprising suspended particulates may enter flow into the funnel of the liquid quality device, and the funnel, together with the weir 420, may induce the liquid into a vortex. At step B, the liquid may pass through the liquid quality device via sump inlet aperture 412 and tube 490 and deeper into the sump region 240. At step C, the liquid propagates into the sump region 240 in the general direction shown by the arrows. Once the liquid passes into the sump region 240, the vortex action may be reduced through detention time and energy losses, partly due to the plurality of drag-inducing portions 450, thereby allowing smaller particulates that were not removed through the cyclonic action of the vortex in the funnel to settle out of the liquid and into the bottom of the sump region 240. At step D, however, some of the liquid flow may try to exit the sump region 240 without reaching the plurality of drag-inducing portions 450 (i.e., short-circuiting). Accordingly, the plate 470 may be positioned above the plurality of drag-inducing portions 450 (drag-inducing portions 450a, 450b, and 450c depicted in FIG. 13) in the sump region 240 in order to direct the liquid flow trying to exit the sump region 240. For example, at step E, some of the liquid flow trying to exit the sump region 240 may be directed back towards the plurality of drag-inducing portions 450 in the sump region 240 by the plate 470. Therefore, the tube 490 and the plate 470 may further ensure that the liquid does not exit the system 400 without treatment to remove particulates from the liquid.

Moreover, while illustrative embodiments have been described herein, the scope includes any and all embodiments having equivalent elements, modifications, omissions, combinations (e.g., of aspects across various embodiments), adaptations or alterations based on the present

disclosure. The elements in the claims are to be interpreted broadly based on the language employed in the claims and not limited to examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive. Further, the steps of the disclosed methods can be modified in any manner, including by reordering steps or inserting or deleting steps. It is intended, therefore, that the specification and examples be considered as example only, with a true scope and spirit being indicated by the following claims and their full scope of equivalents.

What is claimed is:

1. A system for removing particulates from liquid, comprising:

- a base;
- a tubular body extending upwardly from the base, wherein the tubular body comprises an inlet and an outlet;
- a liquid quality device located above the base wherein the liquid quality device comprises:
 - a first region comprising a funnel with a sump inlet aperture;
 - a second region comprising a sump outlet aperture; and
 - a weir positioned between the first region and the second region;
- a sump region located between the base and the liquid quality device;
- a plate positioned in the sump region between the liquid quality device and the plurality of drag-inducing portions, wherein the plate is attached to an internal surface of the tubular body and projects inwardly toward the central axis of the sump region; and
- a plurality of drag-inducing portions positioned in the sump region and projecting inwardly toward a central axis of the sump region, wherein the plurality of drag-inducing portions comprise:
 - a first set of drag-inducing portions;
 - a second set of drag-inducing portions;
 - a third set of drag-inducing portions; and
 - a fourth set of drag-inducing portions,
 wherein the first, second, third, and fourth sets of drag-inducing portions are positioned equidistant from each other and at a same height around a perimeter of the sump region.

2. The system of claim 1, wherein the plate projects inwardly toward the central axis of the sump region such that the plate partially covers a horizontal, cross-sectional area of the sump region.

3. The system of claim 1, further comprising:

- a tube positioned below the sump inlet aperture, wherein the tube extends downwardly from the sump inlet aperture into the sump region.

4. The system of claim 1, wherein:

- the first region is configured to receive a flow of liquid from the inlet of the tubular body and transfer the flow of liquid through the sump inlet aperture of the funnel and into the sump region, and
- the second region is configured to receive the flow of liquid from the sump region through the sump outlet aperture and transfer the flow of liquid to the outlet of the tubular body.

5. The system of claim 1, wherein at least one of the first, second, third, or fourth sets of drag-inducing portions further comprises:

- a first tooth;
- a second tooth located below the first tooth;
- and a third tooth located below the second tooth.

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6. The system of claim 5, wherein teeth of the first set of drag-inducing portions are positioned in a different orientation than teeth of the second set of drag-inducing portions.

7. The system of claim 1, wherein the first, second, third, and fourth sets of drag-inducing portions are attached to respective supporting portions positioned proximate the tubular body in the sump region.

8. A system for removing particulates from liquid, comprising:

- a base;
- a tubular body extending upwardly from the base, wherein the tubular body comprises an inlet and an outlet;
- a liquid quality device located above the base, wherein the liquid quality device comprises:
 - a first region comprising a funnel with a sump inlet aperture;
 - a second region comprising a sump outlet aperture; and
 - a weir positioned between the first region and the second region;
- a sump region located between the base and the liquid quality device;
- a plurality of drag-inducing portions positioned in the sump region and projecting inwardly toward a central axis of the sump region;
- a plate positioned in the sump region between the liquid quality device and the plurality of drag-inducing portions wherein the plate is attached to an internal surface of the tubular body and projects inwardly toward the central axis of the sump region; and
- a tube positioned below the sump inlet aperture, wherein the tube extends downwardly from the sump inlet aperture into the sump region.

9. The system of claim 8, wherein the plurality of drag-inducing portions comprise:

- a first set of drag-inducing portions;
 - a second set of drag-inducing portions;
 - a third set of drag-inducing portions; and
 - a fourth set of drag-inducing portions,
- wherein the first, second, third, and fourth sets of drag-inducing portions are positioned equidistant from each other and at a same height around a perimeter of the sump region.

10. The system of claim 9, wherein at least one of the first, second, third, or fourth sets of drag-inducing portions further comprises:

- a first tooth;
- a second tooth located below the first tooth;
- and a third tooth located below the second tooth.

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11. The system of claim 10, wherein teeth of the first set of drag-inducing portions are positioned in a different orientation than teeth of the second set of drag-inducing portions.

12. The system of claim 9, wherein the first, second, third, and fourth sets of drag-inducing portions are attached to respective supporting portions positioned proximate the tubular body in the sump region.

13. The system of claim 8, wherein the plate projects inwardly toward the central axis of the sump region such that the plate partially covers a horizontal, cross-sectional area of the sump region.

14. The system of claim 8, wherein:
 the first region is configured to receive a flow of liquid from the inlet of the tubular body and transfer the flow of liquid through the sump inlet aperture of the funnel and into the sump region, and
 the second region is configured to receive the flow of liquid from the sump region through the sump outlet aperture and transfer the flow of liquid to the outlet of the tubular body.

15. The system of claim 8, wherein the tube is configured to extend between about 2 inches and about 20 inches downwardly from the sump inlet aperture into the sump region.

16. A system for removing particulates from liquid, comprising:

- a base;
- a tubular body extending upwardly from the base, wherein the tubular body comprises an inlet and an outlet;
- a liquid quality device located above the base, wherein the liquid quality device comprises:
 - a first region comprising a funnel with a sump inlet aperture;
 - a second region comprising a sump outlet aperture; and
 - a weir positioned between the first region and the second region;
- a sump region located between the base and the liquid quality device;
- a plurality of sets of drag-inducing portions positioned equidistant from each other and at a same height around a perimeter of the sump region;
- a plate positioned in the sump region between the liquid quality device and the plurality of sets of drag-inducing portions wherein the plate is attached to an internal surface of the tubular body and projects inwardly toward the central axis of the sump region; and
- a tube positioned below the sump inlet aperture, wherein the tube extends downwardly from the sump inlet aperture into the sump region.

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